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14. ABSTRACT

The focus is on the understanding of the impact phenomenon at relatively low Froude number (Fr = O(1)). In particular, our objectives are to quantify the range of validity of existing asymptotic theories (using the high Froude number assumption, Fr >> 1), and to understand the gravity effect upon the impact process. This study is of direct relevance to accurate prediction of hydrodynamic loads associated with ship slamming and breaking surface wave impact on offshore structures.

15. SUBJECT TERMS

Ship slamming, fully-nonlinear boundary element method, low Froude number water impact, breaking wave impact

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ONR FINAL REPORT

Contract Information

Contract Number	N00014-05-1-0619
Title of Research	Studies on Three-Dimensional Slamming on Slender Ships
Principal Investigator	Dick K.P. Yue
Organization	Massachusetts Institute of Technology (MIT)

Technical Section

Technical Objectives

This study is a joint effort among MIT, Seoul National University (SNU), and Korean Research Institute of Ships and Ocean Engineering (KRISO). The purpose of this study is to investigate the dynamics of three-dimensional slamming for ships operating in severe surface waves using a combined computational and experimental approach. A simulation model has been developed for predicting hydrodynamic loads and impact pressure on the ship due to three-dimensional slamming. A series of laboratory experiments were conducted to validate the numerical model. The major development of the numerical model and laboratory experiments were carried out by SNU/KRISO. The key responsibility of MIT is to investigate the feasibility and effectiveness of advanced computational algorithms for simulating the phenomenon of three-dimensional slamming, and in particular, to understand the water surface impact phenomenon at relatively low Froude number.

Technical Approach

We apply fully nonlinear computations to simulate the water surface impact process of a three-dimensional body in the context of potential flow. The water surface is at calm before the impact starts. As the body enters into the water, the free surface piles up at the intersection with the body. The quadratic boundary-element method with the mixed-Eulerian-Lagrangian approach for free-surface tracking is used to simulate the impact problem in the time domain. Fully nonlinear free-surface boundary conditions in the presence of gravity and nonlinear body boundary conditions are considered. The implementation of the method for the impact problem is similar to that for general nonlinear wave-body interactions as in Liu et al (2001). The thin jet in the neighborhood of the intersection between the body and free surface is generally expected to have a negligible effect on the impact pressure and load on the body. We nevertheless account for this effect using an approach similar to that of Zhao and Faltinsen (1992). With the simulation, the impact pressure distribution on the body, the hydrodynamic loads, and free-surface profile are all computed as a function of time during the impact of an arbitrary body with any Froude number.

Major Results

Though the numerical method implemented is capable of solving the general impact problem with arbitrary three-dimensional body geometry and arbitrary impact velocity, we consider in this study a relatively simple impact problem involving axisymmetric bodies with vertical water entry only. The first canonical problem investigated is the impact of a cone, as shown in figure 1. The solution of this problem can be further simplified as it does not have an apparent physical length scale. For this problem, we can define the Froude number by $Fr = (V/gt)^{1/2}$ (with Vt as the length scale). As a result, the solution of this problem (such as impact pressure and load as well as free-surface profile) is a function of Froude number

Fr and deadrise angle α of the cone only. In the limit of $Fr=\infty$, there exists an asymptotic solution (Shiffman and Spencer 1951).

Figure 2 shows the comparison of the present complete fully-nonlinear solution and the two approximate solutions of Zhao and Faltinsen (1996) for the pressure distribution at a relatively large Froude number $Fr=10$ with two different deadrise angles $\alpha=60^o$ and $\alpha=30^o$. One notes that Zhao and Faltisen (1996) ignored the gravity effect as Shiffman and Spencer (1951). The present solution compares well with the existing solutions of Zhao and Faltinsen (1996) at large Froude number. This provides a validation for the present computation in the case of relatively larger Fr.

Figure 3 plots the total, hydrodynamic, and hydrostatic impact pressure distributions on the cone with $\alpha=60^o$ for Froude number in the range of $Fr=10 \sim 0.75$. In the region near the intersection between the water surface and the body, the hydrodynamic pressure has a strong dependence on the Froude number for $Fr = O(1)$. In general, it increases as the Froude number decreases. Due to the effect of negative hydrostatic pressure, the total impact pressure in this region is generally smaller than that obtained at $Fr=\infty$. In the region away from the intersection part, the hydrodynamic pressure is not much dependent on the Froude number. The total impact pressure in this region is generally larger than that with $Fr=\infty$ and increases as the Froude number decreases due to hydrostatic pressure effect. Similar behaviors of the solution are also obtained for the cone with $\alpha=30^o$, but with more apparent gravity effects for $Fr = O(1)$, as shown in figure 4.

The impact force acting on the body is plotted in figure 5 as a function of the Froude number for $\alpha=60^o$ and $\alpha=30^o$. The plotted force is normalized by $0.5\rho V^2 S$ where ρ is the fluid density and S is the wetted surface of the cone below the mean water surface $z = 0$. For $Fr >\sim 1$, the total impact force is generally dominated by the hydrodynamic effect. For $Fr <\sim 1$, the contribution from the hydrostatic pressure becomes of importance. This effect is more critical for larger α.

Figure 6 compares the free-surface profiles in the region near the intersection of the water surface with the body for various Froude numbers in the range of $Fr=10 \sim 0.35$. For both $\alpha=60^o$ and $\alpha=30^o$, the free-surface profile has a strong dependence on the Froude number when $Fr = O(1)$. In particular, the free-surface may overturn at small Froude numbers. This manifests the gravity effect in water surface impact at low Fr.

Impact/Application

The research is of importance to the development of design tools for reliable prediction of hydrodynamic loads on surface ships due to three-dimensional ship slamming and breaking wave impact.

Publications

Yan, H., Liu, Y. and Yue, D.K.P. 2007 Fully nonlinear computation of water surface impact of axisymmetric bodies. *Proceeding of the Fifth International Conference on Fluid Mechanics, Shanghai, China*

Student Graduated

None

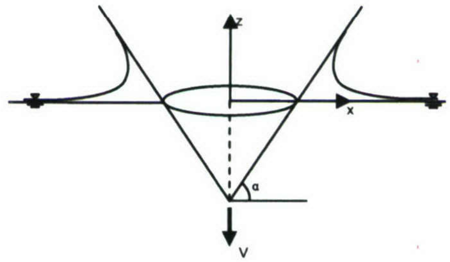
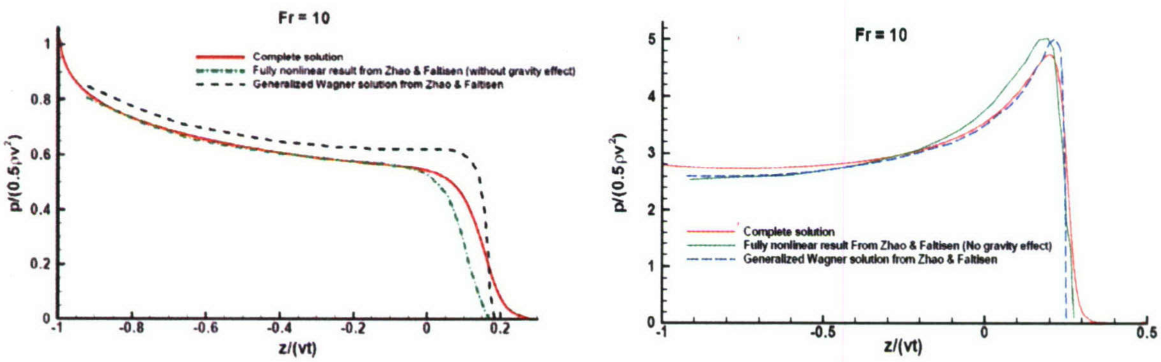
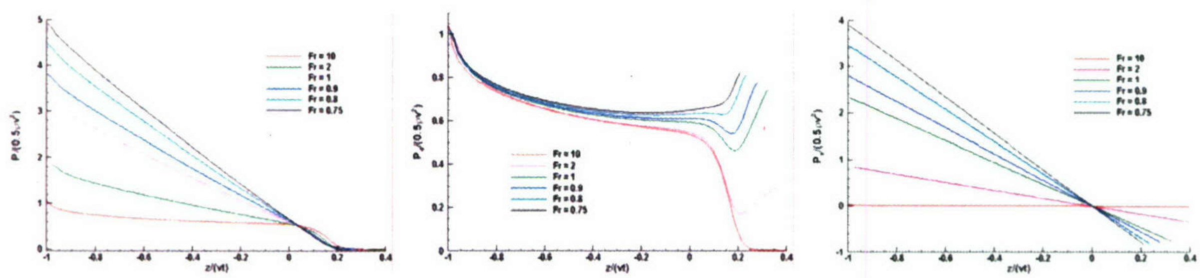


Figure 1:A cone with a deadrise angle of α impacts vertically the water surface at velocity V.



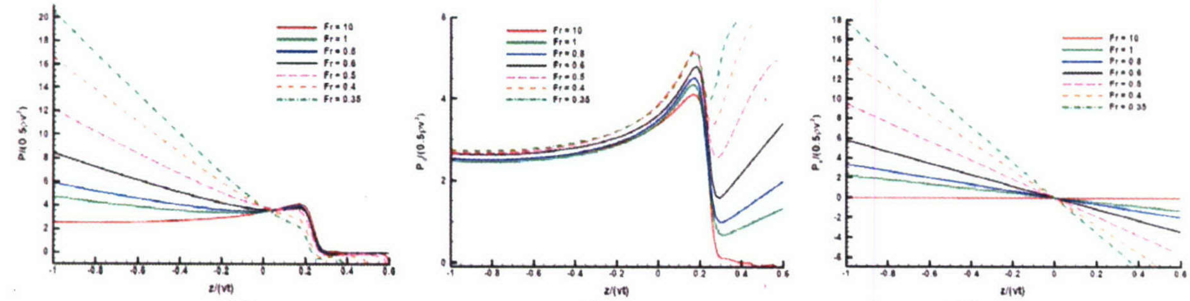
(a) (b)

Figure 2: Comparison of impact pressure distribution on the cone with $\alpha = 60^o$ (a) and $\alpha = 30^o$ (b) at $Fr=(V/gt)^{1/2}=10$ among the present complete fully-nonlinear solution (——), fully-nonlinear but no-gravity-effect solution (– · –) of Zhao and Faltinsen (1996), and the generalized Wagner solution (– – –) of Zhao and Faltinsen (1996).



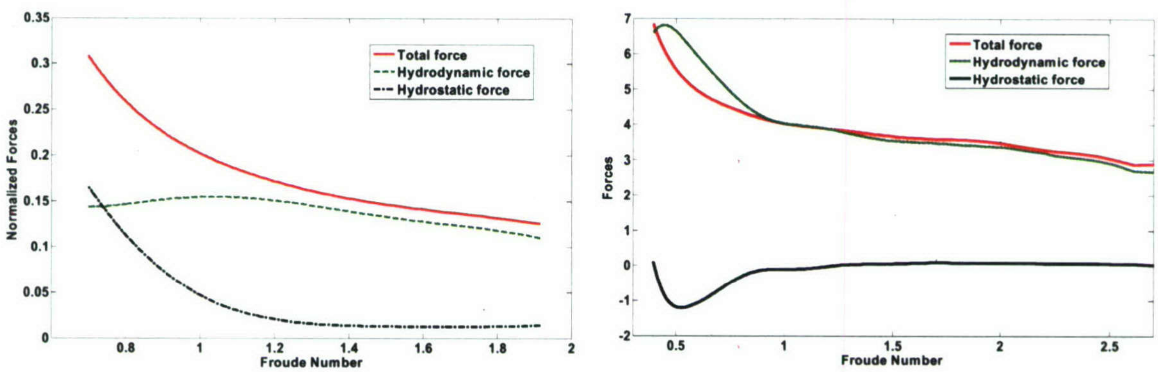
(a) (b) (c)

Figure 3: Total pressure (a), hydrodynamic pressure (b), and hydrostatic pressure (c) on the cone with $\alpha = 60^o$ as a function of Froude number.



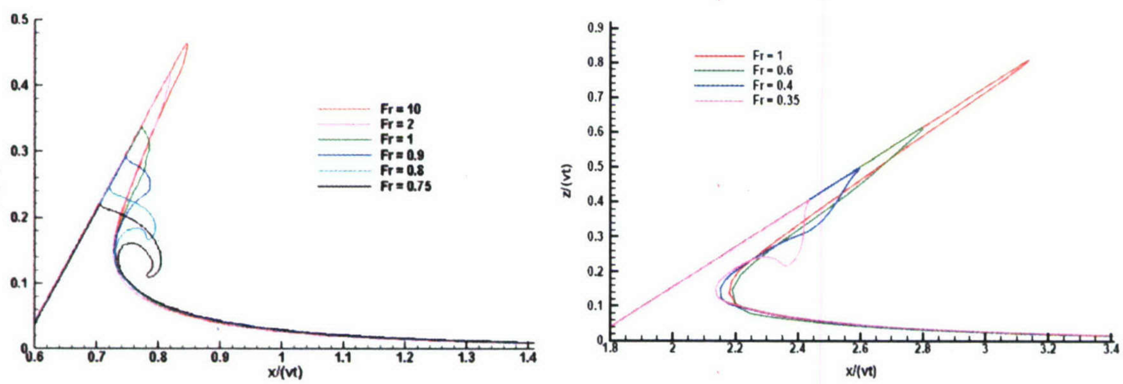
(a) (b) (c)

Figure 4: Total pressure (a), hydrodynamic pressure (b), and hydrostatic pressure (c) on the cone with $\alpha = 30^{\circ}$ as a function of Froude number.



(a) (b)

Figure 5: Total forces on the cone with $\alpha = 60^{\circ}$ (a) and $\alpha = 30^{\circ}$ (b) as a function of Froude number.



(a) (b)

Figure 6: Free-surface profiles in the neighborhood of the intersection between the water surface and the body at various Froude numbers for a cone with $\alpha = 60^{\circ}$ (a) and $\alpha = 30^{\circ}$ (b).

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